

REMARKS

Reconsideration of this application is respectfully requested. Claims 1 to 21 are under active examination. Claims 22 and 23 have been cancelled without prejudice.

Rejection under 35 USC 112, second paragraph

Claims 22 and 23 stand rejected under this heading as being indefinite for failing to particularly point out and distinctly claim the subject matter which applicant regards as the invention. These claims have been cancelled without prejudice, rendering the rejection moot.

Rejection under 35 USC 103

Claims 1 to 21 stand rejected under this heading as being unpatentable over WO99/09439 (WO'439) in combination with Lee *et al*, Witzgall *et al* and Patil *et al*. Applicant respectfully traverses this rejection.

The Examiner states that WO'439 discloses a method for forming a photonic crystal material having a three dimensional periodic structure, which method comprises steps as claimed. However, the Examiner acknowledges that WO'439 fails to specifically disclose the photosensitive material as defined in present claim 1 which possesses an average number of cross-linkable groups per molecule of at least three with an equivalent weight per cross-linkable group of at most 1000.

The Examiner alleges that this deficiency in the teaching of WO'439 is remedied by each of Witzgall *et al*, Lee *et al* and Patil *et al*. Each of these references is said to disclose the use of the resin known as EPON-SU-8 (from Shell

Chemical) in the formation of 3-D structure. The Examiner concludes as a consequence that it would have been obvious to use SU-8 in the method of WO'439 and that this combination would provide a process and material as claimed in the present application.

In reply, it is submitted that the selection of a photosensitive material possessing the two essential characteristics of (1) an average number of cross-linkable groups per molecule of at least three and (2) an equivalent weight per cross-linkable group of at most 1000, for use in the method of WO'439, would not have been obvious over the prior art. The photonic crystal material produced in accordance with the presently claimed method is a holographically defined photonic crystal structure having uniform 3-dimensional periodicity following exposure to an interference pattern generated by coherent interference of UV laser radiation. The achievement of technical advantages, by using a photosensitive material as defined in present claim 1 such as the resin SU-8, is neither taught nor foreshadowed in the references relied on by the Examiner. Thus the references do not make it obvious to one skilled in the art that an SU-8-containing resist would be suitable for making photonic crystal structures having the above-mentioned properties.

The present inventors have identified three key properties associated with photosensitive materials having the essential characteristics (1) and (2) mentioned above and specified in claim 1. The three key properties are:

- (a) The transparency of the thick films;
- (b) The effect of cross-linked density on the solubility contrast between

heavily exposed and lightly exposed resist; and preferably,

- (c) The latency of the chemical cross-linking, initiated by photo-excitation, that permits the use of multiple exposures.

These three properties are not highlighted as desirable properties in WO 439.

Furthermore, as will be discussed below, Lee *et al*, Patil *et al* and Witzgall *et al* do not provide any indication that these properties are, or would be, associated with SU-8 resists.

(a) *Transparency.* To enable the uniform holographic fabrication of a 3-D photonic crystal in a thick resist, transparency at the irradiation wavelength must be very high, i.e. >95%, otherwise the extent of photo-polymerisation at the bottom surface of the film will be smaller than at the top. If the transparency is too low, the repeated building block of the crystal will decrease in size with increasing depth. Since the structural uniformity of these blocks is essential for the formation of the optical bandgap, and this is the property which gives photonic crystals their utility, a very high transparency resist is essential to this process.

The issues of transparency are discussed in some detail on page 3 of the present application (see in particular lines 15-29). This section teaches that if the correct photo-acid generator is used in the correct concentration relative to the epoxy precursor, then the necessary combination of transparency and insolubility following exposure can indeed be attained. The requisite uniformity in the resulting crystal is apparent in Figure 1 of the present application.

In the two-photon method described in Witzgall *et al*, the transparency of SU-8

at the IR 800nm laser wavelength is effectively 100%. Two-photon absorption coefficients are extremely small, so there is almost no attenuation of the incident light through the thickness of the resist, and no constraint on the thickness of the material. As a result of this approach Witzgall *et al* is silent on whether the commercial SU-8 product used in that work would be sufficiently transparent to meet the requirements for the holographic definition of a photonic crystal, when a *single photon UV* laser exposure is applied.

Lee *et al* and Patil *et al* indicate the suitability of SU-8 for *thick* resist applications, but this does not imply that it is suitable for 3-dimensional patterning. A two-dimensional lithographic pattern is defined by a shadow mask, so that particular volumes of the resist are either exposed or not exposed. For the resist to be adequately exposed, only a small portion of the incident light needs to reach the bottom surface. Substantial absorption through the depth of the resist can be tolerated, because the exposure time can always be made long enough to ensure that the bottom surface becomes insoluble, without affecting the solubility of those parts of the resist that are shadowed by the mask. The transparency of the resist is therefore *not* a critical parameter – although, to avoid overlong exposure times, it ought to exceed ~ 10%.

In Lee *et al* (Figure 1, page 3012) the transmission of a 100  $\mu\text{m}$  thick film of SU-8 resist at 365 nm is quoted as 46%. At the 355nm wavelength of the laser described in the present application, the transmission deduced from Figure 1 would be ~5%. These figures are acceptable for planar mask exposures, but indicate a

degree of absorption that is far too large for 3-dimensional holographic lithography. Under such conditions, were the required pattern to be well-defined at the top surface, there would be no polymerisation at all at the bottom surface. In other words, rather than disclosing the utility of SU-8 for making a uniform, thick, photonic crystal, Lee *et al* contains data indicating its *unsuitability*.

(b) *Solubility Contrast*. This property is important because the dose in a holographic exposure varies continuously and smoothly across the pattern. If the features of the structure are to have sharply defined edges, then the dependence of the solubility on the exposure must display a very sharp threshold.

Page 1, line 26 onwards of the present application discloses that the sharpness of this threshold can be accentuated by choosing a resin, such as SU-8, with very high cross-linking functionality. The present inventors have established that the property of solubility contrast is of key importance because it permits the smoothly varying holographic intensity pattern to define a crystal composed of well-defined, sharp-edged, structural units.

By contrast, in conventional lithography such as used in Lee *et al*, and Patil *et al*, the edge of the mask ensures a sharp discontinuity in the exposure. It is therefore *not* possible to conclude from the characteristics of structures produced using masks, such as those described in Lee *et al* and Patil *et al*, that SU-8 has sufficient solubility contrast to allow uniform features with sharp edges to be obtained from a smoothly varying intensity pattern.

Lee *et al* discloses that SU-8 patterns with 16  $\mu\text{m}$  features sizes can be

formed using optical masks (see page 3012, column 2 second paragraph). However there is no indication in Lee *et al* that the very much smaller 0.5  $\mu\text{m}$  feature resolution, required to form photonic crystals for use in the visible spectrum, is achievable under holographic conditions. According to Lee *et al* electron-beam lithography is capable of sub-0.1  $\mu\text{m}$  resolution, but because of the much higher exposure resolution of this method, this fact provides no guidance on the resolution limit for an optical exposure. The present application discloses for the first time the achievement of sub-micron resolution in this material, under holographic illumination.

(c) *Latency*. The thermal activated step in the photo-initiated polymerisation of the class of epoxy resin which includes SU-8 means that the image is latent prior to heating. Neither Lee *et al* nor Witzgall *et al* nor Patil *et al* discusses this feature of SU-8. By permitting multiple exposures, well separated in time, it is possible to produce much more flexible photonic crystal devices; this is as described at page 4 lines 25-29 of the present application. This property of SU-8 and its analogues is not taught in the prior art.

It is submitted that the favourable properties of the photosensitive material as defined in present claim 1 were not taught or suggested in the cited references, nor was it derivable from the cited references that the use of such a photosensitive material in the method of WO'439 would provide a photonic crystal material having technical advantages over prior art materials, in particular the advantages mentioned above.

In further rebuttal of the rejection of the claims under 35 USC 103 it is

respectfully submitted that it would not have been obvious to combine the teachings of the cited references in the first place. This is because there are considerable differences between the method of WO'439 and the methods taught in each of Lee *et al*, Patil *et al* and Witzgall *et al*. A person of skill in the art seeking to develop the method of WO'439 would not therefore have consulted Lee *et al*, Patil *et al* or Witzgall *et al* for guidance, as will be shown.

Lee *et al* and Patil *et al* teach that SU-8 (or related) resists can be used to define *thick* structures, e.g. 30 to 200  $\mu\text{m}$ . However, in contrast to WO'439, these references do not address the issues that arise if patterning is required in the direction normal to the plane of the resist. The examples in these references are patterned only within a two dimensional plane. In the third dimension (the direction normal to the plane) the resist is unpatterned i.e. it is uniform and continuous between the substrate and its top surface. This is a key difference between the methods of Lee *et al* and Patil *et al* on the one hand, and WO'439 on the other.

Lee *et al* and Patil *et al* also describe the use of low intensity single photon UV exposures through planar masks. A two dimensional photographic pattern is defined by a shadow mask, so that particular volumes of the resist are either exposed or not exposed. Masks are not used in the method of WO'439 (see page 4, line 2). This therefore represents a second important difference between the methods.

Witzgall *et al* teaches that SU-8 resists can be used to fabricate three dimensionally patterned structures using high intensity two photon IR (800nm) exposure. This exposure is carried out on a voxel-by-voxel basis, within a thick

(~25 $\mu$ m) layer. Two photon absorption, as used in Witzgall *et al*, is a very inefficient "non-resonant" process, requiring very high intensities before any light can be absorbed and any polymerisation initiated. Such high intensities can be achieved at the focus of a microscope objective using very short laser pulses, as reported in Witzgall *et al*. However, the region in which polymerisation occurs is then extremely small. For this reason it takes a long time (in the order of hours) to create all the component parts of a photonic crystal of a necessary size, piece by piece, by moving the focal point about systematically within the resist. This method contrasts with that of WO'439 in which use is made of the much higher absorption probability of a one photon absorption to create a uniform single exposure of all the necessary structure.

The above comments show that a person of ordinary skill in the art would not have combined WO'439 with any of the other three cited references because they relate to different methods. In consequence, the fact that SU-8 could be used in the methods of Lee *et al*, Patil *et al* and Witzgall *et al* does not suggest, or render obvious, its suitability for use in the method of WO'439.

It is submitted that in the light of the above arguments claims 1 to 21 can be acknowledged as non-obvious. Accordingly, the rejection under this heading should be withdrawn.

Rejection under 35 USC 102(b) and/or Rejection under 35 USC 103(a)

Claim 23 was rejected under these headings as being unpatentable over Witzgall *et al*. In response, claim 23 has been cancelled without prejudice. This objection is consequently rendered moot.



Double Patenting

Claims 1 to 21 stand rejected under the judicially created doctrine of obviousness-type double patenting as being unpatentable over claims 1 to 20 of US Patent 6,358,653 (Turberfield) in view of Lee *et al*, Witzgall *et al* and Patil *et al*. Turberfield is derived from WO'439 and therefore discloses identical subject matter. Applicant submits that, for the reasons discussed above in relation to the rejection of claims 1 to 21 under 35 USC 103(a), the subject matter claimed in the present application is non-obvious over this combination of documents. Accordingly, the rejection for obviousness type double patenting over Turberfield should be withdrawn.

Conclusion

It is submitted that claims 1 to 21 currently under examination are both novel and non-obvious over the prior art. Accordingly, favorable reconsideration of the application is respectfully requested.

A fee sheet is attached for the extension. If other fees are needed, please charge them to deposit account 17-0055.

Respectfully submitted,  
Andrew J. Turberfield *et al*.

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By:



Richard T. Roche  
Registration No. 38,599  
Quarles and Brady LLP  
411 East Wisconsin Ave.  
Milwaukee, WI 53202  
(414) 277-5805

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